

## ICECUBE: THE CUBIC KILOMETER NEUTRINO TELESCOPE AT THE SOUTH POLE

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Search for ultra high-energy neutrino induced reactions, as part of a comprehensive probe of the neutrino sky and also investigation of the particle nature of the dark matter, with unique sensitivity to cold dark matter particles are described. We present a description of the design, scientific motivation and goals, performance and status of the IceCube experiment.

### 1. Introduction

The main motivation for the IceCube experiment <sup>1</sup> is to probe the universe with ultra high energy (UHE) neutrinos and to search for the signature of cold dark matter. The IceCube detector will provide astrophysical and particle physics information, essential to the understanding of the origin of the highest energy cosmic rays as well as a test of the fundamental laws of physics.

The all-particle spectrum, as shown in Figure 1, is dominated by two main features at 3 PeV and at 5 EeV commonly referred to as the "knee" and the "ankle". The spectrum shows a steep drop in the flux of cosmic rays as a function of energy. The slope becomes steeper at the knee and rises at the ankle. Many attempts have been made to explain the drop and increase in the flux at the knee and the ankle, respectively with diverse fortune (see for example Esteban Roulet <sup>2</sup> and references therein).

In the UHE region of the knee, the particle flux drops to  $1/m^2\text{-year}$  and falls to  $1/km^2\text{-year}$  at the ankle. These fluxes are impossible to observe by conventional detectors. The detection of these particles with reasonable

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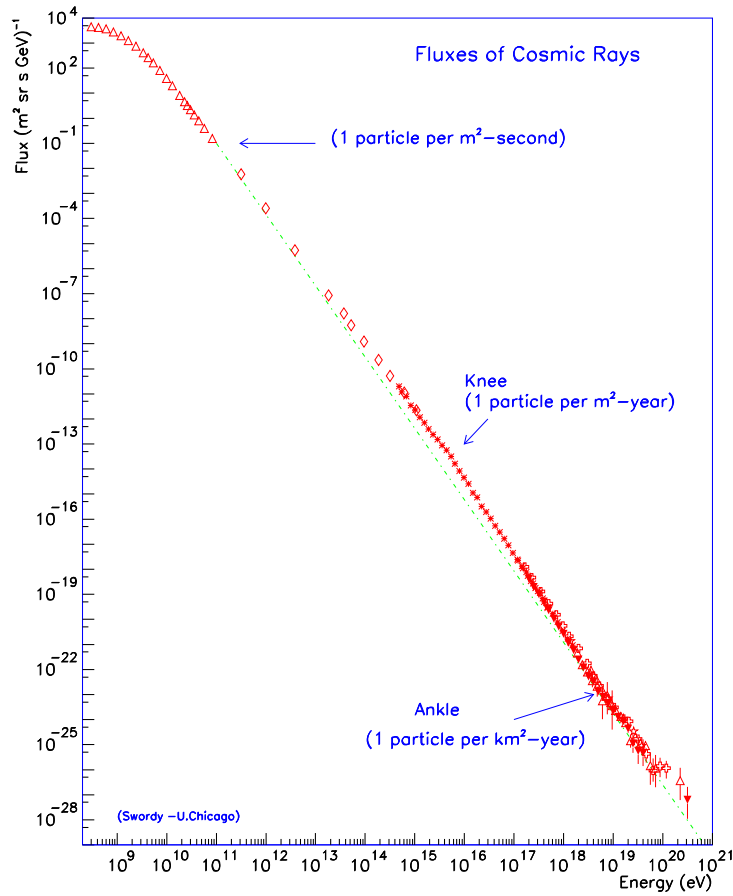


Figure 1. All-particle energy spectrum

statistics will provide the necessary information regarding sources and the nature of these particles. Therefore, at the scale of the IceCube detector, one can begin to perform efficient neutrino detection in the PeV region, above where the "knee" in the all-particle spectrum occurs.

IceCube is designed to search for sources of UHE neutrinos such as Active Galactic Nuclei (AGN), Supernova Remnants (SNR) or micro-quasars, and neutrinos from Gamma Ray Bursts (GRB). The sensitivity of IceCube

to astrophysical sources has been studied in reference <sup>4</sup>.

Aside from a search for Astrophysical sources of neutrinos, IceCube can also provide answers to a series of questions, related to particle physics, such as search for neutrinos from possible candidates for cold dark matter, weakly interacting massive particles (WIMPs) annihilating in the sun, and magnetic monopoles or other exotic particles such as strange quark matter or Q-balls predicted by SUSY models <sup>5</sup>. Furthermore, IceCube with its cubic kilometer size is able to examine a possible enhancement in neutrino interaction cross sections due to extra dimensions where graviton contributions could increase the total neutrino cross section to the level of hadronic interaction cross sections, of the order of tens of mb<sup>6</sup>.

## 2. IceCube Detector Setup

The IceCube detector layout is shown in Figure 2. IceCube consists of 4800 optical modules (OM) mounted on 80 strings regularly spaced such that each two adjacent strings are 125 m apart. In planar view, IceCube covers an area of approximately 1 km<sup>2</sup>. The instrumented part of the string is at a depth of 1,450 to 2,450 m below the surface of the ice. Each PMT string consists of 60 OM's, with OM's equally spaced at a distance of approximately 17 m. The strings are arranged in a hexagonal pattern in planar view. At the ice surface, on the top of each string, a station of the IceTop air shower array will be installed. An IceTop station consists of two ice tanks with a total area of 7 m<sup>2</sup>. Two of these tanks have been installed during the 2003-04 season at the South Pole. The IceTop will be operated in coincidence with the in-ice arrays. This provides a veto for the downward going events as well as information on the chemical composition of the cosmic rays up to 10<sup>18</sup>eV <sup>7</sup>. The AMANDA-II detector <sup>3</sup> will be integrated into IceCube. The present configuration is designed for optimum sensitivity to muon neutrinos in the energy range of 1-100 TeV.

## 3. The Digital Optical Module

The heart of the Data Acquisition system of IceCube is the Digital Optical Module (DOM). The IceCube DOM shown in Figure 3 contains a 10-inch diameter PMT, HAMAMATSU R-7081. These PMT's provide excellent charge and time resolution. The dynamic range is 200 photo-electrons (pe)/10 nsec, with an integrated dynamic range of more than 2000 pe's. The signal is digitized at the PMT level with a digitization depth of 4  $\mu$ -sec.

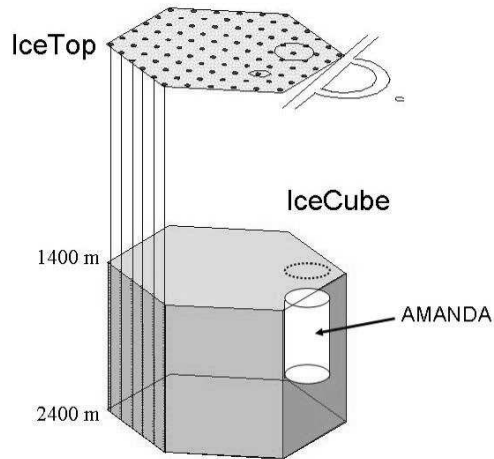


Figure 2. IceCube, IceTop and AMANDA

A single PMT low noise rate of less than 500 Hz, at operating temperatures of the South Pole of  $-20$  to  $-40$  °C has been achieved with these PMT's. Each PMT and its associated electronics is housed in a glass sphere that can withstand a pressure of 10,000 psi (68,948 kPa). The face of the PMT makes contact with this glass shell through a gel with approximately the same index of refraction as that of the glass.

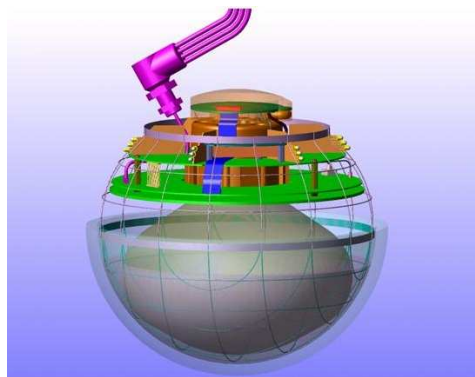


Figure 3. Schematic view of the IceCube DOM

#### 4. IceCube Performance

The main particle detection capability of the IceCube detector is measured in terms of its sensitivity to the detection of muons. Muons are produced in the detector because of charged-current interactions of  $\nu_\mu$  with H and O nuclei in the ice or other nuclei in the ground below the ice. The majority of the downward-going muons in IceCube are due to the interaction of the primary cosmic rays with the atmosphere. Figure 4 summarizes the expected sensitivity to diffuse fluxes as a function of neutrino energy. Solid lines show the expected 90% confidence level (CL) limits for  $E^{-2}$  and  $E^{-1}$  fluxes, respectively. These calculations assume a period of three years of data accumulation. The dashed lines show the model proposed by Stecker and Salamon describing the photo-hadronic interactions in the AGN core<sup>9</sup>. The dotted line shows the model of Mannheim, Protheroe, and Rachen, estimating neutrino emission from photo-hadronic interactions in AGN jets<sup>10</sup>. Also shown is the GRB estimate of Waxman and Bahcall<sup>12</sup>. Their estimate yields approximately ten GRB events for 1000 GRB's monitored. IceCube performance at higher energies is described by Yoshida, Ishibashi, and Miyamoto. They show that in the 10 - 100 PeV energy range, not only muons, but also  $\tau$ 's survive without decay and would leave detectable signals in horizontal and downward-going events<sup>8</sup>.

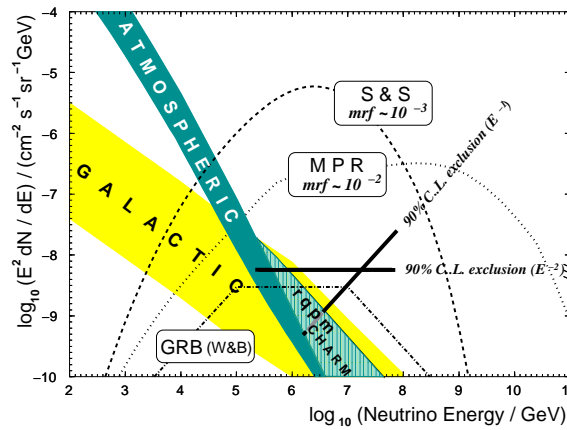


Figure 4. Expected sensitivities of the IceCube detector. See text for explanations.

## 5. IceCube Deployment

The hot-water drill technology has been developed and perfected over decades as the fastest and the most efficient method for drilling holes in the ice. It turns out that for IceCube hot water also provides the only possible technology. Water is readily available and the water in the hole after deployment of the strings freezes, preserving the optical properties of the ice. The optics for IceCube are well understood from years of experience with AMANDA. Holes with 60 cm diameter will be drilled with 100 °C water at a rate of 16 holes per year. The drill system is an evolution of the AMANDA drill called the Enhanced Hot Water Drill (EHWD). The EHWD drill is energy intensive because of the large amount of energy required for the ice-to-water phase transition. The total time required to drill a 2400 m deep hole is about 40 hours. The power consumption for the EHWD will be 5 MW, compared to 2 MW for AMANDA. This, and the larger diameter and the length of the water transporting hoses, will result in 40 hours needed to drill a 2400 m deep hole. Mounting, testing and deployment of a string with 60 DOM's are estimated to take about 20 hours.

## 6. IceCube Status

The IceCube collaboration includes about 150 scientists from institutions in Belgium, Germany, Japan, Netherlands, New Zealand, Sweden, UK, US and Venezuela. In the US IceCube is funded by the National Science Foundation through a multi-year Major Research Equipment (MRE) grant. The start-up funding for a period of two years from the NSF began in 2002. This year (2004) IceCube has begun its implementation phase as a fully funded NSF, MRE. Furthermore, significant funding for the IceCube project has been approved in Belgium, Germany and Sweden. Full IceCube construction has begun this year and will take 6 years. The first parts of the EHWD's have been shipped to the pole. This year the production and testing of 150 DOM's have been scheduled. The drilling of the first holes is scheduled to begin in January 2005.

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